PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : F02M 25/07, F02B 25/26, 75/10, F02F 1/22 — A1

(11) International Publication Number: **WO 94/28300**

(43) International Publication Date: 8 December 1994 (08.12.94)

(21) International Application Number: PCT/AU94/00270

(22) International Filing Date: 25 May 1994 (25.05.94)

(30) Priority Data:
PL 9163 2 June 1993 (02.06.93) AU

(71) Applicant *(for all designated States except US)*: ORBITAL ENGINE COMPANY (AUSTRALIA) PTY. LIMITED [AU/AU]; 1 Whipple Street, Balcatta, W.A. 6021 (AU).

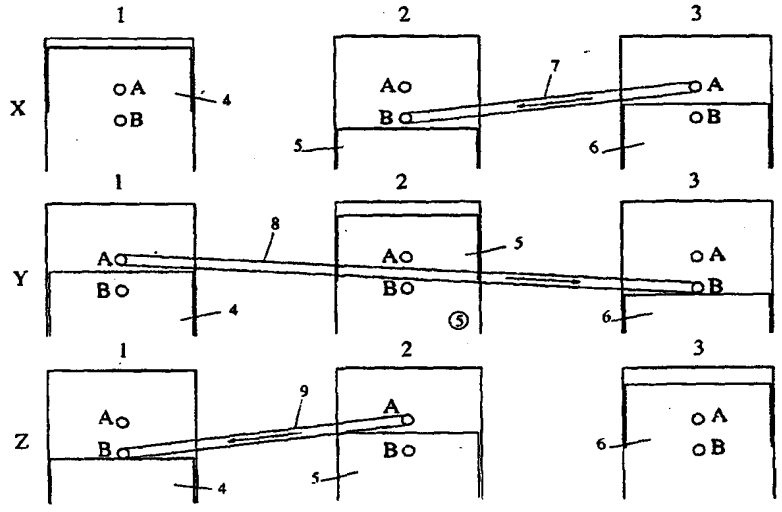
(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: BROOKS, Roy, Stanley [AU/AU]; 8 Beadman Court, Wembley, W.A. 6167 (AU). HOUSTON, Rodney, Alexander [AU/AU]; 5 Adenmore Way, Kingsley, W.A. 6062 (AU).

(74) Agent: WATERMARK PATENT & TRADEMARK ATTORNEYS; 4th floor, Durack Centre, 263 Adelaide Terrace, East Perth, W.A. 6004 (AU).

(81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, ES, FI, GB, GE, HU, JP, KG, KP, KR, KZ, LK, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG).

Published
With international search report.

(54) Title: MULTICYLINDER INTERNAL COMBUSTION ENGINE WITH EXHAUST GAS RECIRCULATION



(57) Abstract

A method of operating an internal combustion engine having a plurality of cylinders (1, 2, 3) and pistons (4, 5, 6) respectively supported therein. During an expansion stroke of the piston (4, 5, 6) of at least one of the cylinders (1, 2, 3), combusted gas from said at least one cylinder is delivered to at least one other cylinder. Delivery is effected by the pressure differential between the gases in the at least one cylinder supplying the gas and the at least one other cylinder receiving the gas. Further, the gas is delivered from the at least one cylinder to the at least one other cylinder independently of the exhaust system of the engine.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	**GB**	United Kingdom	**MR**	Mauritania
AU	Australia	**GE**	Georgia	**MW**	Malawi
BB	Barbados	**GN**	Guinea	**NE**	Niger
BE	Belgium	**GR**	Greece	**NL**	Netherlands
BF	Burkina Faso	**HU**	Hungary	**NO**	Norway
BG	Bulgaria	**IE**	Ireland	**NZ**	New Zealand
BJ	Benin	**IT**	Italy	**PL**	Poland
BR	Brazil	**JP**	Japan	**PT**	Portugal
BY	Belarus	**KE**	Kenya	**RO**	Romania
CA	Canada	**KG**	Kyrgystan	**RU**	Russian Federation
CF	Central African Republic	**KP**	Democratic People's Republic of Korea	**SD**	Sudan
CG	Congo			**SE**	Sweden
CH	Switzerland	**KR**	Republic of Korea	**SI**	Slovenia
CI	Côte d'Ivoire	**KZ**	Kazakhstan	**SK**	Slovakia
CM	Cameroon	**LI**	Liechtenstein	**SN**	Senegal
CN	China	**LK**	Sri Lanka	**TD**	Chad
CS	Czechoslovakia	**LU**	Luxembourg	**TG**	Togo
CZ	Czech Republic	**LV**	Latvia	**TJ**	Tajikistan
DE	Germany	**MC**	Monaco	**TT**	Trinidad and Tobago
DK	Denmark	**MD**	Republic of Moldova	**UA**	Ukraine
ES	Spain	**MG**	Madagascar	**US**	United States of America
FI	Finland	**ML**	Mali	**UZ**	Uzbekistan
FR	France	**MN**	Mongolia	**VN**	Viet Nam
GA	Gabon				

MULTICYLINDER INTERNAL COMBUSTION ENGINE WITH EXHAUST GAS RECIRCULATION

This invention relates to internal combustion engines and particularly internal combustion engines operating on the two stroke cycle and to the management of the combustion process thereof to control the level of contaminants in the exhaust emissions.

It has in the past been recognised that conventional two stroke cycle engines exhibit poor performance in the area of fuel consumption and also in the area of the level of harmful emissions in the engine exhaust. However, there are substantial benefits to be obtained by wider use of engines operating on the two stroke cycle, firstly, because of their relatively simple construction, and secondly, because of their relatively small physical size and resultant high power to weight ratio. There has accordingly been considerable development in two stroke cycle engines in recent years to control the combustion process thereof in a manner to reduce the level of emissions in the exhaust, and/or reduce the fuel consumption.

It has been recognised that the introduction of exhaust gas back into the fuel/air mixture prior to the ignition thereof can contribute to a reduction in the production of NO_X (oxides of nitrogen) during the combustion process, as the presence of the exhaust gas in the fuel/air mixture tends to reduce the resultant temperature and pressure conditions in the engine cylinder during combustion which is contrary to the high temperature and pressure conditions which promote the creation of NO_X. This process of mixing exhaust gas with the fuel/air mixture is commonly referred to as exhaust gas recirculation (EGR) and is typically achieved by bleeding a controlled quantity of exhaust gas from the exhaust system into the air induction manifold of the engine.

Although this procedure has been used to some success in four stroke cycle engines, it is generally not as effective when applied to two stroke cycle engines due principally to the low level of vacuum existing upstream from the conventional throttle in the air induction system and the poor distribution of the exhaust gas which would result if under certain operating conditions it was to be admitted to the air induction system downstream of the throttle.

There is disclosed in the applicant's co-pending International Patent Application No. PCT/AU94/00009 a method of introducing exhaust gas into the fuel/air mixture of a two stroke cycle engine, whereby effective control of the amount and distribution of the exhaust gas can provide beneficial results in the management of exhaust emissions. In this prior application, the disclosed method of operating a two stroke cycle crankcase scavenged internal combustion engine comprises selectively delivering exhaust gas from a location downstream of the engine exhaust port directly into the engine crankcase to be delivered together with air in the crankcase to the engine combustion chamber, and controlling the quantity of exhaust gas delivered to the crankcase each engine cycle in accordance with engine operating conditions.

Further, there is also disclosed in the applicant's co-pending Australian Patent Application No. PL9164, a modification to the method and apparatus as disclosed in the above referred to International Patent Application No. PCT/AU94/00009 whereby exhaust gas can be selectively introduced into the air induction system.

In each of these previous proposals, the exhaust gas is taken from the exhaust system downstream of the exhaust port and thus usually requires some form of external componentry to take the already exhausted gas and reintroduce this gas either indirectly or directly into one or more combustion chambers of the engine. This arrangement normally requires some form of external duct work to direct a portion of the exhaust gas into the fresh air or air and fuel charge for admission therewith into one or more combustion chambers of the engine. Such constructions represent an additional cost arising from the necessity to manufacture additional componentry and to subsequently assemble same to the engine block and its ancillaries. Thus, additional manufacturing and installation costs are incurred.

Further, each of the above referred to pending patent applications propose the introduction of the exhaust gas to the combustion chamber of a two stroke cycle engine via the engine crankcase. Thus, each proposal involves exposing the environment within the crankcase to exhaust gas which, under certain circumstances or conditions, may lead to adverse effects in engine

operation and/or durability of components such as reed valves, the crankshaft and connecting rod bearings.

It is the object of the present invention to provide a method and apparatus for enabling the use of exhaust gas recirculation on an engine to contribute to the control of exhaust emissions therefrom but to achieve this end in a manner which will minimise the additional costs arising therefrom during manufacture and which is effective in operation and in achieving the desired level of management of the combustion process and reducing contamination of the crankcase environment.

With this object in view there is provided a method of operating an internal combustion engine having a plurality of cylinders and pistons respectively supported therein, wherein during an expansion stroke of the piston of at least one of the cylinders, combusted gas from said at least one cylinder is delivered to at least one other cylinder, said delivery being effected by the pressure differential between the gases in the at least one cylinder supplying the gas and the at least one cylinder receiving the gas. The gas is preferably delivered independently of an exhaust system of the engine.

More specifically, there is provided a method of operating an internal combustion engine having a plurality of cylinders and pistons respectively supported therein, said method including communicating at least one cylinder during an expansion stroke of the piston therein with at least one other cylinder of the engine during a compression stroke of the piston therein, said communication being effected when the pressure differential in the communicating cylinders establishes a flow of combusted gas from the at least one cylinder to the at least one other cylinder. The communication is preferably independent of an exhaust system of the engine.

Preferably, each cylinder of the engine is arranged to supply combusted gas to a first said cylinder and receive combusted gas from a second said cylinder.

The above method may also conveniently include the step of cooling the combusted gas during transfer thereof.

There is also provided according to the present invention an internal combustion engine having a plurality of cylinders and pistons respectively supported therein, the engine including means arranged to provide communication between at least one cylinder and at least one other cylinder, whereby combusted gas from the at least one cylinder during an expansion stroke of the piston therein is passed to the at least one other cylinder during a compression stroke of the piston therein due to the pressure differential therebetween. The communication between the cylinders is preferably independent of an exhaust system of the engine.

Preferably, each cylinder of the engine communicates with two other cylinders for providing combusted gas to one of the cylinders and for receiving combusted gas from the other one of the cylinders.

Conveniently, each said cylinder has a port in the wall thereof communicating with a port in the wall of another cylinder, said ports being located in the respective cylinders so that during the expansion stroke of the piston within one of said cylinders, combusted gas passes to another of said cylinders during the compression stroke of the piston therein. Preferably, the communication between respective cylinders is provided by at least one conduit which, at the respective ends thereof, communicates with the ports in the cylinder walls at different levels in respect to the travel of the piston within the cylinders. The location of the ports in the respective cylinders with respect to the piston stroke determines the pressure differential that causes the combusted gas to pass from one cylinder to the other and hence determines the rate of flow of combusted gas during the period in which the cylinders are in communication.

At least one cylinder may be arranged to deliver combusted gas during the respective expansion stroke of the piston therein to a gallery or passage which is in turn connected to at least one other cylinder at a location of lower pressure during the cycle of operation thereof so that combusted gas can pass from the gallery or passage into said at least one other cylinder. Conveniently, suitable ports are provided in the wall of each cylinder for the supply of combusted gas to the gallery or passage, and further ports are provided in the wall of each cylinder for the discharge of combusted gas from the

gallery or passage to each cylinder. The ports of each cylinder may be located at different levels in respect to the travel of the piston within the cylinder.

In order to assist in increasing the mass of combusted gas supplied to the respective cylinders, it is preferable that during the passage from one cylinder to another, the combusted gas is subject to a degree of cooling. This may be achieved by locating the gallery or the passage conveying the combusted gas adjacent the cooling system of the engine and/or by providing specific cooling to the passages, ducts or galleries, by cooling means such as cooling fins on the periphery thereof, or a specific jacket through which a cooling medium such as water or air is passed.

In some constructions, individual valve means may be provided on the respective ports or on one of each two intercommunicating ports. Where a common duct or gallery is used to receive and/or supply combusted gas to or from more than one cylinder, it may be necessary to provide appropriate valves associated therewith or like controls that may be selectively operated to provide communication between the passage or gallery and the respective cylinders supplying or receiving combusted gas. The valves may be appropriate pressure activated valves or may be of the controlled type such as by a programmed electronic control mechanism.

The method and apparatus disclosed herein for providing combusted gas to the cylinders of a multi-cylinder engine as a means of controlling the combustion process of the engine and thereby reducing undesirable emissions such as NO_X, has the advantage that it is independent of the engine exhaust system and that the combusted gases do not come in contact with areas of the mechanisms of the engine which may be adversely affected by the presence of combusted gas such as the air control system in the air intake duct and reed valves, bearings and other components in the case of crankcase scavenged two stroke cycle engines.

The method and apparatus as disclosed herein may be used exclusively to recycle combusted gas to the combustion chambers of an engine for the purposes of emission control or it may be used in conjunction with other forms of exhaust gas recirculation such as those disclosed in the pending

applications of the applicant as identified hereinbefore or any other form of exhaust gas recirculation.

It will be convenient to further describe the invention by reference to the accompanying drawings which illustrate one possible embodiment of the invention. Other embodiments of the invention are possible and consequently the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

In the drawings:

Figure 1 is a series of schematic representations of a three cylinder two stroke cycle engine showing the interconnection between respective cylinders; and

Figure 2 is a diagrammatic representation of a flattened engine cylinder showing the port location therein.

In the schematic of Figure 1 the engine cylinders are designated 1, 2 and 3, and it is to be understood that the pistons of the respective cylinders numbered 4, 5 and 6 are connected to a common crankshaft (not shown) in the conventional manner and are respectively 120° out of phase with each other about the axis of the crankshaft. In the wall of each of the cylinders 1, 2 and 3, there are provided two small ports designated A and B which hereinafter, shall be identified by the combined notation of the cylinder and the port notation, thus, in cylinder 1 the ports will be identified as 1A and 1B, in cylinder 2, 2A and 2B and in cylinder 3, 3A and 3B. It will be noted that the ports A and B are displaced from one another in the direction of the axis of the cylinders 1,2,3 and thus, as the pistons 4,5,6 move down from the top dead centre position, the port A will firstly be uncovered so as to provide communication with the area of the cylinders 1,2,3 above the level of the pistons 4,5,6 and at a later point in the piston travel, the port B will be exposed and communicated with the combustion chamber above the level of the pistons 4,5,6. As can be seen in Figure 2, the port A is located above the level of both the exhaust port 10 and the main and auxiliary transfer ports 11 and 12 of the cylinders 1,2,3 and accordingly, the port A will be exposed for communication with the combustion chamber prior to the commencement of the exhaust of the combustion gases through the exhaust

port 10, and also prior to the opening of the main and auxiliary transfer ports 11 and 12.

Further, the port B is located so that it will be in communication with the combustion chamber whilst the exhaust port 10 and transfer ports 11 and 12 are also in communication with the combustion chamber. However, the port B will be closed prior to the closing of the exhaust 10 and transfer ports 11 and 12. Both the port A and B are located on the side of the cylinders 1,2,3 opposite the exhaust port 10.

The three representations X, Y and Z of the three cylinder engine as shown in Figure 1 represent respectively the relative disposition of the respective pistons 4,5,6 of the engine when they are in their top dead centre position, that is, in X, the piston 4 is at the top dead centre position in cylinder 1, in Y, the piston 5 is at the top dead centre position in cylinder 2, and in Z, the piston 6 is at the top dead centre position in cylinder 3. For the sake of clarity, the communicating passages 7,8 and 9 between the respective ports A and B are only shown in configurations X, Y and Z where the ports A and B at the respective ends of the passages 7,8,9 are exposed and thus combustion gas is flowing therealong.

Referring now to representation X in Figure 1, port 3A is in communication with port 2B via the passage 7 thereby permitting combustion gas to flow from cylinder 3 to cylinder 2. In representation Y, the ports 1A and 3B are in communication via the passage 8 with the gas flowing from cylinder 1 to cylinder 3. Finally, in representation Z, port 2A is in communication with port 1B whereby combustion gas passes from cylinder 2 to cylinder 1 via the passage 9.

It will be appreciated that in the representations as shown in Figure 1, there is continuous communication between the respective ports by the passages 7, 8 and 9. However, there is not always a gas flow though these passages 7,8,9. For example, in representation X, there is no flow between ports 2A and 1B as the timing of the pistons 4,5,6 is such that the piston 4 of cylinder 1 is at the top dead centre position therefore blocking off port 1B. Accordingly, the passage 9 is pressurised and there is no flow of gas from cylinder 2 to cylinder 1. Similarly, no gas flow occurs between ports 1A and 3B

in representation due to the respective locations of the pistons 4 and 6 within cylinders 1 and 2.

In some engine configurations, it may be appropriate to incorporate in each of the passages 7, 8 and 9 a control valve to enable a further control to be exercised over the duration and/or timing of the flow of gases between the cylinders 1,2,3 connected by the respective passages 7,8,9. In such a situation, appropriate valves would be incorporated in the passages 7, 8 and 9, these being under the control of an ECU programmed in accordance with the required timing and duration of the communication.

As previously indicated, two or more of the ports A and B may be in communication with a distribution gallery to permit the required flow of combustion gas to the respective cylinders 1,2,3 prior to commencement of combustion therein.

The present invention has been described in an application relating to a two stroke internal combustion engine, however, it is to be appreciated that the invention can also be adapted for four stroke engine applications.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of operating an internal combustion engine having a plurality of cylinders and pistons respectively supported therein, wherein during an expansion stroke of the piston of at least one of the cylinders, combusted gas from said at least one cylinder is delivered to at least one other cylinder, said delivery being effected by the pressure differential between the gases in the at least one cylinder supplying the gas and the at least one cylinder receiving the gas.

2. A method according to claim 1, wherein the gas is delivered independently of an exhaust system of the engine.

3. A method of operating an internal combustion engine having a plurality of cylinders and pistons respectively supported therein, said method including communicating at least one cylinder during an expansion stroke of the piston therein with at least one other cylinder of the engine during a compression stroke of the piston therein, said communication being effected when the pressure differential in the communicating cylinders establishes a flow of combusted gas from the at least one cylinder to the at least one other cylinder.

4. A method according to claim 3, wherein said communication is independent of an exhaust system of the engine.

5. A method according to any one of the preceding claims, wherein each cylinder of the engine is arranged to supply combusted gas to a first said cylinder and receive combusted gas from a second said cylinder.

6. A method according to any one of the preceding claims, further including the step of cooling the combusted gas during transfer thereof.

7. An internal combustion engine having a plurality of cylinders and pistons respectively supported therein, the engine including means arranged to provide communication between at least one cylinder and at least one other cylinder, whereby combusted gas from the at least one cylinder during an expansion stroke of the piston therein is passed to the at least one other cylinder during a compression stroke of the piston therein due to the pressure differential therebetween.

8. An engine according to claim 7, wherein the communication between the cylinders is independent of an exhaust system of the engine.

9. An engine according to claim 7 or 8, wherein each cylinder of the engine communicates with two other cylinders for providing combusted gas to one of the cylinders and for receiving combusted gas from the other one of the cylinders.

10. An engine according to any one of claims 7 to 9, wherein each said cylinder has a port in the wall thereof communicating with a port in the wall of another said cylinder, said ports being located in the respective cylinders so that during the expansion stroke of the piston within one of said cylinders, combusted gas passes to another of said cylinders during the compression stroke of the piston therein.

11. An engine according to claim 10, wherein the communication between respective cylinders is provided by at least one conduit which, at the respective ends thereof, communicates with the ports in the cylinder walls at different levels in respect to the travel of the piston within the cylinders.

12. An engine according to any one of claims 7 to 9, wherein at least one cylinder is arranged to deliver combusted gas during the expansion stroke of the piston therein to a gallery or passage which is in turn connected to at least one other cylinder at a location of lower pressure during the cycle of operation

thereof so that combusted gas can pass from the gallery or passage into said at least one other cylinder.

13. An engine according to claim 12, wherein suitable ports are provided in the wall of each cylinder for the supply of combusted gas to the gallery or passage, and wherein further ports are provided in the wall of each cylinder for the discharge of combusted gas from the gallery or passage to each cylinder.

14. An engine according to claim 13 wherein the ports of each cylinder are located at different levels in respect to the travel of the piston within the cylinder.

15. An engine according to any one of claims 12 to 14, wherein the gallery or the passage conveying the combusted gas is located adjacent to the cooling system of the engine for providing cooling for the combusted gas.

16. An engine according to any one of claims 11,12 to 14, wherein cooling means are provided on the engine for providing cooling for the combusted gas during transfer thereof.

17. An engine according to any one of claims 10,11,13 or 14, wherein individual valve means are provided on the respective ports or on one of each two intercommunicating ports.

18. An engine according to claim 11, wherein individual valve means are provided on the or each conduit.

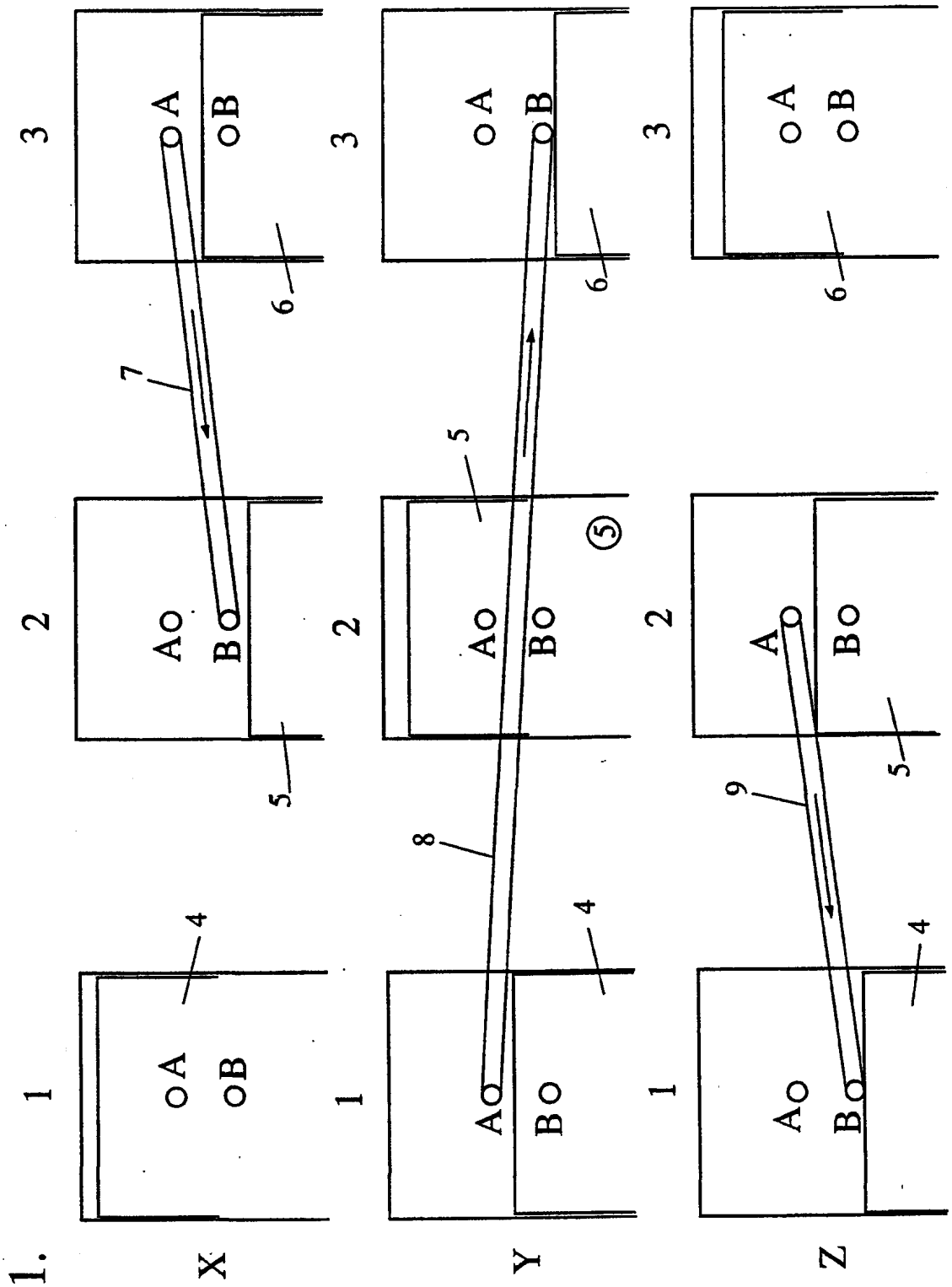


Fig 1.

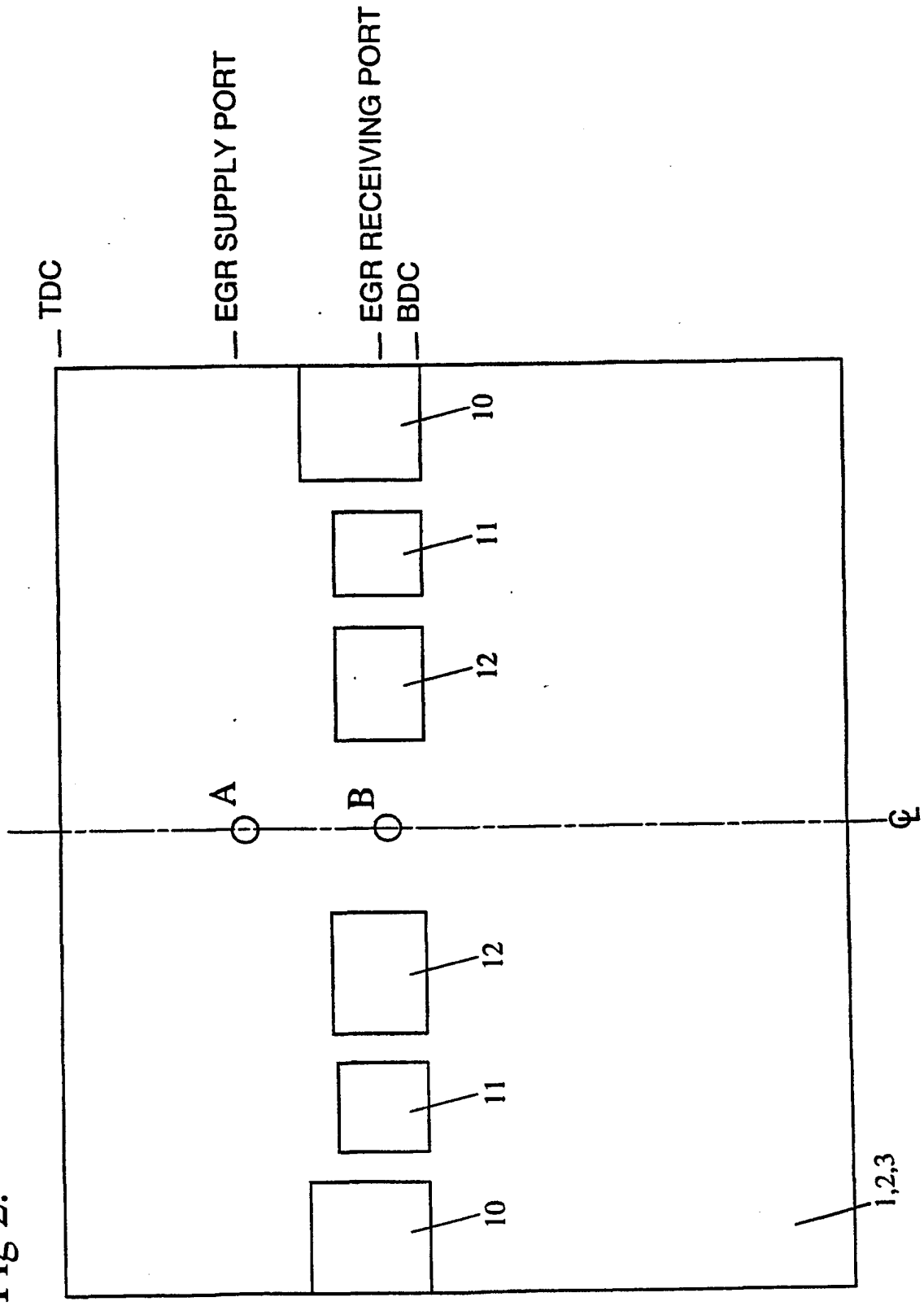

TDC
EGR SUPPLY PORT
EGR RECEIVING PORT
BDC
10
11
12
A
B
12
11
10
1,2,3

Fig 2.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU 94/00270

A. CLASSIFICATION OF SUBJECT MATTER
Int. Cl.[5] F02M 25/07, F02B 25/26, 75/10, F02F 1/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC : F02M 25/06, 25/07, F02B 25/26, 75/10, F02F 1/22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU : IPC as above and F02B 47/08

Electronic data base consulted during the international search (name of data base, and where practicable, search terms used)
DERWENT

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
X	AU,B, 79926/87 (590458) (WALBRO CORPORATION) 12 May 1988 (12.05.88) whole document	1-4, 7-8, 12
X	US,A, 4422430 (WIATRAK) 27 December 1983 (27.12.83) whole document	1-4, 7-8, 12
X	Derwent Abstract Accession No. 86-136059/21, Class Q25, SU,A, 1186-815 (ALTAI POLY) 23 October 1985 (23.10.85) abstract	1-2

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 August 1994 (03.08.94)	1 Sept 1994 (01.09.94)

Name and mailing address of the ISA/AU

AUSTRALIAN INDUSTRIAL PROPERTY ORGANISATION
PO BOX 200
WODEN ACT 2606
AUSTRALIA

Facsimile No. 06 2853929

Authorized officer

C.M. WYATT

Telephone No. (06) 2832538

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate of the relevant passages	Relevant to Claim No.
X	FR,A, 2564141 (ALDAYAR) 15 November 1985 (15.11.85) whole document	1-2
A	AU,B, 14078/20 (WEGE) 11 January 1921 (11.01.21) Figures 1, 2 and 4	

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	4422430	DE	3138332	IT	1145123	PL	228178
AU	79926/87	CA US	1278475 4787343	EP	266610	JP	63124860

END OF ANNEX